Photos & Fusion Newsletter

Lab Announces Fusion-Fission Energy Project

With the help of California Gov. Arnold Schwarzenegger, Lawrence Livermore National Laboratory (LLNL) announced plans on Nov. 10 to develop an advanced energy concept called LIFE, short for Laser Inertial Fusion-Fission Energy.

After touring LLNL's National Ignition Facility (NIF), Gov. Schwarzenegger held a press conference to discuss the nearly completed laser and its applications, particularly the LIFE project. The governor said LIFE, a hybrid nuclear power plant that combines the best features of fusion and fission energy, could help meet the state's and the nation's future energy needs while simultaneously decreasing dependence on fossil fuels and helping reduce greenhouse gas emissions that contribute to climate change.

Gov. Schwarzenneger, LLNL Director George Miller, and NIF Director Ed Moses at the post-tour news conference.

"This laser technology has the potential to revolutionize our energy future"

—Governor Arnold Schwarzenegger

"This laser technology has the potential to revolutionize our energy future," Schwarzenegger said. "If successful, this new endeavor could generate thousands of megawatts of carbon-free nuclear power but without the drawbacks of conventional nuclear plants. This type of innovation is why we are a world leader in science, technology and clean energy, and I could not be prouder that this work is happening right here in California."

LIFE represents a breakthrough technology that would lead to sustainable, carbon-free energy that is safe, dramatically shrinks the nation's and the world's inventories of nuclear waste and minimizes the danger of nuclear proliferation. For more information, visit the LIFE Website at lasers.llnl.gov/missions/energy_for_the_future/life.

Photons & Fusion is a monthly review of science and technology at the National Ignition Facility & Photon Science Principal Directorate, Lawrence Livermore National Laboratory. For more information, submit a question at lasers.llnl.gov/forms/contact_us.php.

November 2008

This Month in Photons & Fusion

Probing Warm Dense Matter with X-ray Scattering

LLNL researchers and colleagues in the United States and Europe have developed a new technique for understanding warm dense matter (WDM), a complex and little-explored state of matter that occurs during inertial confinement fusion experiments such as those planned for NIF.

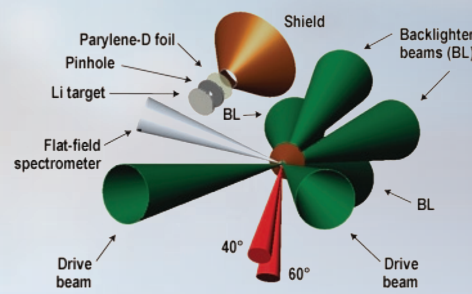
WDM is characterized by temperatures usually associated with plasmas but at densities similar to solids. In addition to shedding light on the implosion phase of controlled thermonuclear fusion, the study of WDM also represents laboratory analogues of astrophysical environments found in the core of planets and the crusts of old stars.

Because it has properties common to both solids and plasmas, WDM presents severe challenges to experimental characterization and theoretical modeling. In a *Nature Physics* paper published online on Oct. 19 (*doi:10.1038/nphys1103*), the researchers show how WDM states can be diagnosed and structural properties can be obtained using inelastic X-ray scattering measurements on a compressed lithium sample. The thermodynamic properties–temperature, density and ionization state–were measured using a combination of non-invasive, high accuracy X-ray diagnostics and advanced numerical simulations. The experiment revealed that the matter at the center of planets is in an intermediate state between a solid and a gas over lengths larger than 0.3 nanometers. The results showed that extreme matter behaves as a charged liquid, but at smaller distances it acts more like a gas.

The X-ray scattering experiment was conducted on the Vulcan laser at the Rutherford Appleton Laboratory in Chilton, U.K., and was aimed at the observation of the long-wavelength limit of the ion response in shock-driven matter. The researchers found that in this limit, the system behaves as a single fluid that can be studied using hydrodynamical laws.

"The study of warm dense matter states, in this experiment on lithium, shows practical applications for controlled thermonuclear fusion," said Gianluca Gregori of LLNL and the University of Oxford, "and it also represents significant understanding relating to astrophysical environments found in the core of planets and the crusts of old stars. This research therefore makes it not only possible to formulate more accurate models of planetary dynamics, but also to extend our comprehension of controlled thermonuclear fusion where such states of matter, that is liquid and gas, must be crossed to initiate fusion reactions.

"This work expands our knowledge of complex systems of particles where the laws that regulate their motion are both classical and quantum mechanical," Gregori said.



Setup of the experiment, showing the shock drive and backlighter beams; the target assembly with a cone shield to avoid undesired signal on the detector, the parylene-D foil, the 170-μm collimating pinhole and the Li target; and the line of sight of the flat field spectrometer and the 60° and 40° positions for the time-integrated Von Hamos spectrometer. The backlighter beams are all fired inside the cone shield onto the parylene-D foil, while the drive beams are fired onto the Li sample.

NIF Receives 'Green Enterprise' Award

The NIF & Photon Science directorate has been named a winner of an "Empower the Green Enterprise" award from Oracle Corporation. The award, a crystal plaque, was presented at the September Oracle Open World conference in San Francisco. The award recognizes customers from a wide range of industries that use Oracle products to support green business practices and sustainability initiatives in order to reduce environmental impact and costs and improve business efficiencies. NIF used Oracle software in its integrated computer control automation system, as well various database applications including procurement.

X-ray Scattering of Shock-Compressed Matter

NIF & Photon Science researchers Andrea Kritcher, Siegfried Glenzer and colleagues have demonstrated the capability to measure temperature and density in dense matter during shock compression with ten-picosecond temporal resolution. The technique, reported in the Oct. 3 edition of the journal *Science (DOI: 10.1126/science.1161466)*, will be useful in inertial confinement fusion experiments that achieve extreme densities, such as those on NIF.

Shock wave heating is a key technique to produce matter at extreme conditions in the laboratory in which the physics of planetary formation and modeling of planetary composition can be tested. Contemporary experiments are designed to determine the equation of state (EOS) of light elements or to measure effects of shock waves on matter – for example, to investigate effects by solar nebula shocks. In addition, the inertial confinement approach to controlled nuclear fusion uses a deuterium-tritium filled capsule that will be compressed to 1,000 times solid density and heated to temperatures higher than the interior of the Sun by using a sequence of coalescing shock waves.

Previous shock wave experiments have been restricted to measuring particle and shock velocities. The experiments reported in the *Science* article directly measured the thermodynamic properties and dynamic structure factors of shocked matter. These experiments have become possible with the advent of penetrating powerful X-ray probes produced by high-energy (300 J) petawatt-class ultra-short-pulse lasers.

The researchers shock-compressed lithium-hydride, LiH, with an energetic nanosecond laser and measured the conditions with spectrally resolved X-ray Thomson scattering. These pump-probe experiments show that efficient compression and heating occur at temperature and density conditions previously not accessible to quantitative *in situ* characterization. At shock coalescence, the researchers observed rapid heating to temperatures of 25,000 kelvins when the scattering spectra show the collective plasmon oscillations that indicate the transition to the dense metallic plasma state. The plasmon frequency determines the material compression, which was found to be a factor of three, thereby reaching conditions in the laboratory relevant for studying the physics of planetary formation.

The K-a X-ray source used in the study also provides the same number of X-ray photons on target as projected for future X-ray free electron laser facilities. This indicates that X-ray Thomson scattering experiments on dense matter will soon be accessible for high-repetition measurements of thermodynamic properties with 20- to 200-femtosecond temporal resolution.

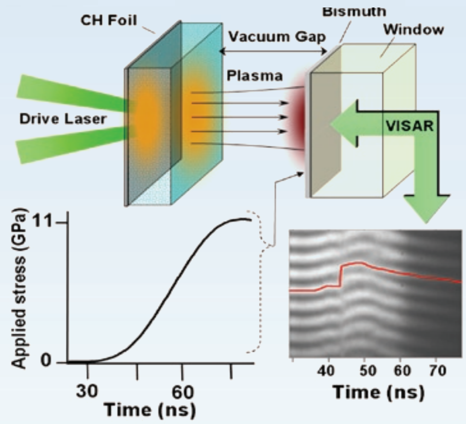
A New Way to Study Phase Transition Kinetics

NIF researchers have demonstrated a new experimental technique for studying phase-transformation kinetics.

Pressure-induced structural phase-transformation kinetics has been an active area of theoretical and experimental research in condensed-matter physics for several decades. Despite this, there remains a lack of quantitative data, primarily due to the limitations in experimental techniques to measure these extremely rapid phenomena.

To explore structural phase-transformation kinetics under dynamic loading conditions, a NIF research team led by Gilbert W. (Rip) Collins employed a laser-driven ramp-wave loading technique at high strain rates to study time-dependent effects on phase transformations in bismuth preheated to 296-532 kelvins and ramp compressed with 15-35 nanosecond rise times to a peak stress of about 11 gigapascals.

According to Collins, the researchers discovered a new strain-rate-dependent effect on phase transitions. “That is, if the strain rate is high enough, the phase boundary appears to move,” Collins said. “In fact, above a critical strain rate, the apparent phase transition pressure increases logarithmically with strain rate. This is likely a new fundamental scaling law for kinetics of phase transitions and gives insight into the phase transition mechanism.”



Target design for laser-driven ramp compression of a bismuth foil.

A description of the research was the cover article in the August 8 issue of *Physical Review Letters (Phys. Rev. Lett. 101, 065701 (2008))*.

New Tool Removes HMDS Coating Flaws

Anti-reflective coatings are applied to the surface of optical devices to reduce reflection, which improves the efficiency of the system as less light is lost. Sol-gel technology is a convenient process for coating large optics requiring a high laser damage threshold and outstanding antireflective coatings.

In many high energy laser systems such as NIF, optics with a HMDS (hexamethyldisalizane) sol-gel antireflective coating are placed in close proximity to each other. During the coating process, halo-shaped coating flaws develop in the sol around digs (pits or small craters on the polished optical surface) and particles. Depending on the shape and size of the flaw, they may have a high probability of modulating and damaging optics downstream when the laser is fired.

To prevent these flaws from causing damage, NIF chemical engineer Marcus Monticelli has developed a coating flaw removal tool that deploys a spot of decane, an alkane hydrocarbon, with a syringe and dissolves away the coating flaw. The residual liquid is vacuum removed, leaving a circle approximately 1mm in diameter. The remaining coating-free spot has a low probability of causing downstream damage.

Monticelli presented a paper describing the tool at the September SPIE Boulder Damage Symposium in Boulder, Colorado.

Measuring Hohlraum Conversion Efficiencies

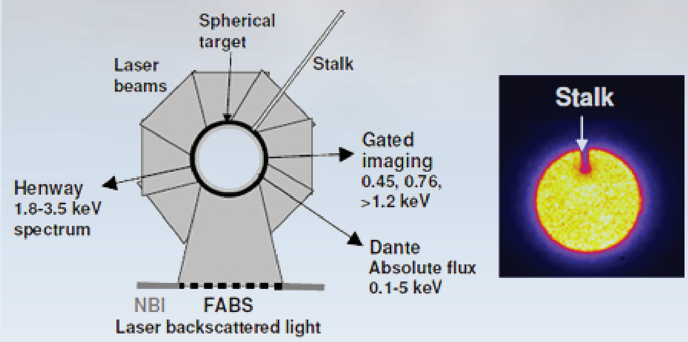
In ignition experiments during the National Ignition Campaign, NIF’s 192 laser beams, frequency converted to ultraviolet (351-nanometer, or 3ω) wavelength, will heat the interior of a hohlraum, generating X-rays that compress a deuterium-tritium fuel capsule inside the hohlraum and bring it to ignition and thermonuclear burn.

In order to benchmark the atomic physics models used in hydrodynamic simulations employed for NIF ignition designs, a NIF research team led by Eduard Dewald, in collaboration with a research team from the Commissariat à l’Énergie Atomique (CEA) in France, have measured the conversion efficiency of 351-nm laser light to soft X-rays (0.1-5 keV) with high precision for three hohlraum wall material candidates – gold, uranium and high-Z (high-atomic-number) mixtures, known as "cocktails."

Previous research has shown that compared to gold, uranium and cocktails have demonstrated improved X-ray radiation confinement and uniformity at the capsule due to reduced losses in the hohlraum walls. Furthermore, they have reduced "M-band" (~2-4 keV) radiation that can preheat the capsule. The remaining question is: How do cocktails and/or pure uranium compare to gold with respect to conversion efficiency?

To help answer that question, the research team conducted a series of experiments at the OMEGA Laser Facility at the University of Rochester. The team used 60 flattop laser pulses smoothed with phase plates to achieve constant and uniform laser intensities of 10^{14} and 10^{15} W/cm^2 onto the targets – parameters that are relevant for the future ignition experiments on NIF. The absolute X-ray flux was measured in a time- and spectrally-resolved fashion via a multi-channel power diagnostic, while incident and laser scattering measurements were used to calculate the laser coupling onto the target.

After several hundreds of picoseconds, the soft X-ray conversion efficiencies were measured to reach fairly constant and impressively high plateau values of 95 percent at 10^{14} W/cm^2 and 80 percent at 10^{15} W/cm^2 for all hohlraum materials. These values are higher than previously reported, as they are normalized by the laser power coupled into the target rather than the incident light. Furthermore, while at 10^{14} W/cm^2 laser intensity the M-band flux is negligible (~1 percent), at 10^{15} W/cm^2 it is significant and ranges from 10 percent (for uranium) to 27 percent (for gold) of the total flux.



The experimental setup for soft X-ray conversion efficiency measurements. At right is an X-ray emission image.

LASNEX computer simulations, performed by LLNL's Mordy Rosen, show good agreement with measurements in conversion efficiency and X-ray spectra, but the currently used atomic physics model somewhat underestimates the M-band flux. There is currently very active work on implementing a better atomic physics model.

A report on the team's findings, "X-ray conversion efficiency of high-Z hohlraum wall materials for indirect drive ignition," was recently published in *Physics of Plasmas (Phys. Plasmas 15, 072706 (2008); DOI:10.1063/1.2943700).*

DPAL Sets Peak Power Record

The Photon Science & Applications Program's Diode-Pumped Alkali Laser (DPAL) is a new class of laser that combines features of both gas and solid-state lasers, based on diode excitation of atomic alkali vapors. Being developed under the sponsorship of the U.S. Missile Defense Agency, DPAL recently achieved a major milestone, demonstrating a peak output power of 100 watts in a laboratory demonstration at LLNL.

This peak-power record demonstration represents a number of other firsts in the DPAL community, demonstrating capabilities directly applicable to power-scaled systems of the future:

- It is the first demonstration at this peak power level of a hydrocarbon-free DPAL, furthering this approach as the only viable route to reliable power-scaled systems.
- It is the only demonstration to date of a DPAL using diode arrays that are easily scaled to the extreme power levels required for megawatt-class demonstrations. Others in the community are using 10- to 20-GHz-wide excitation sources that are too large, complicated and expensive to be considered for power scaling.
- This is the first demonstration of a DPAL system that uses a scalable pump-guiding geometry, an essential component of any power-scaled system. A high performance 36-layer zirconia/alumina coating on sapphire was developed for this application.

These results are for 100-µsec-duration pulses and a 3-cm-long static alkali vapor cell. Near-term follow-on experiments are being planned for 6-cm, 9-cm and 12-cm-long cells to aid in determining the optimum Rb number density for final power-scaled designs.

This series of measurements is being anchored against modeling codes that are being used in the specification and design of the next-generation flowing vapor cell that will enable true continuous operation.

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